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Ship Hydromechanics Department

Departmental Report

SEAKEEPING DESIGN STUDY OF FUTURE COMBATANTS

by

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DTRC/SHD-1317-01 Seakeeping Design Study of Future Combatants

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NOMENCLATURE

B	Beam
C_B	Block coefficient
C_M	Midship section coefficient
C_P	Prismatic coefficient
C_{WP}	Waterplane area coefficient
C_{WPA}	Waterplane area coefficient aft of midships
C_{WPF}	Waterplane area coefficient forward of midships
C_{VP}	Vertical prismatic coefficient
C_{VPA}	Vertical prismatic coefficient aft of midships
C_{VPF}	Vertical prismatic coefficient forward of midships
FP	Forward Perpendicular
g	Acceleration of gravity
GM	Transverse metacentric height
KG	Height of center of gravity above baseline
KM	Height of metacenter above baseline
L	Length at the waterline
LBP	Length Between Perpendiculars
MS	Midships
T	Draft at midships, (station 10)
T_ϕ	Natural roll period
Δ	Displacement (tonnes)

ABSTRACT

Round table discussions held at the David Taylor Research Center have generated the concept of a Scout Fighter and a Carrier of Large Objects as possible warships of the future. Many considerations regarding these vessels (i.e. size, endurance, mission) are still under discussion. This report details the seakeeping study of four Scout Fighter hull forms and two Carrier of Large Objects variants. The hull forms were optimized for seakeeping. Operability calculations were performed for purposes of comparison with existing ships.

ADMINISTRATIVE INFORMATION

This investigation was sponsored by the Naval Sea Systems Command, SEA 011 via the Surface Ship Combatant Ship R and D Group, CHENG-R, Program Element 63564N, Revolution at Sea. The work was performed by Code 1561 of DTRC during FY89 under work unit number 1-1203-940.

INTRODUCTION

According to Disguise, Decoy, Defend, and Supply (D^3S) concepts, the battle force of the future is to have two ship classes. The objective is to reduce the number of differences between ships, so the important ships will be harder to target and attack. All the ships in a given class will have the same hull form regardless of mission. This will allow for cheaper construction costs due to learning curve effects, modular construction, and economies of scale when purchasing.

Of particular importance to the performance of future warships is the improvement of seakeeping qualities. History has demonstrated that ships are required to operate in adverse conditions including strong winds, precipitation, and heavy seas. The most influential condition which affects seakeeping quality is the effect of ocean waves. When sea conditions worsen, the operational capability of a ship decreases due to excessive motions. Degradations can range from mild cases of motion sickness to severe restrictions on equipment operability.

The first, and smaller of the two classes, is the Scout Fighter (SF). The Scout Fighter is to be a fast attack type of combatant which can operate in high sea states.

The Scout Fighter needs to be capable of operating well ahead of the Battle Group while conducting screening operations. This mission statement appears to be similar to that of a fast frigate. Reduced manning and minimal maintenance are very desirable vessel characteristics. Cost considerations are also important. Many considerations regarding this type of vessel (i.e. size, endurance, mission) are still under discussion. In response to these questions, a brief seakeeping study was conducted to further this decision process. Two classes of Scout Fighters were evaluated. One class included a stand alone vessel similar to a frigate. A second class involved smaller vessels which would be deployed from the well deck of the Carrier of Large Objects (CLO).

The second class of ships, the Carrier of Large Objects (CLO), is much larger than the Scout Fighter and is to perform tasks currently performed by aircraft carriers, amphibious assault ships, oilers, and logistics ships. In addition to Scout Fighters, this report deals with the amphibious (CDA) and logistics (CDL) variants of the CLO. The CLO is much more defined than the SF and the seakeeping study was to answer the questions of whether the selected hull form had good seakeeping performance and could it be improved.

CONSTRAINTS

SCOUT FIGHTER

Two groups of Scout Fighters were considered. The first group was the Stand Alone Scout Fighter (SASF). As the size of these ships had not been previously determined, three displacements were chosen to represent the range of possible sizes. Maximum displacement under consideration was arbitrarily fixed at 6000 LT. The hull form was optimized individually for each of three displacements (6000, 4000, and 2000 LT). The second group under consideration involves small SF having a CLO as a mother ship (CLOSF). The main constraint on the CLOSF, was that it fit in the CLO well deck.

CARRIER OF LARGE OBJECTS

The CLO variants were more defined than the Scout Fighter. A prototype CDA hull form was provided by the sponsor, and referred to as CDA in this report. As a result, the optimization of the CLO variants was more constrained. For each variant, two optimal hull forms were developed. The first allowed the draft to vary, while length, beam, and displacement were fixed. These are denoted by CDL0 and CDA0. The second hull form fixed the draft along with the length, beam, and displacement. These are denoted by CDL1 and CDA1. All the form coefficients were allowed to vary for each hull form.

ASSUMPTIONS

SCOUT FIGHTER

Several assumptions were made to facilitate seakeeping design. First, maximum speed must be addressed. It takes little understanding of Target Motion Analysis (TMA) to realize that the Scout Fighter requires a speed advantage over other ships in the Battle Group. This is necessary to allow the Scout Fighter to successfully patrol large areas ahead of the main force of a Battle Group which is traveling at base speed. A 30 to 35 knot design speed was chosen as a reasonable goal for non-planing monohulls.

Seakeeping hull designs must be made with appropriate attention paid to powering requirements. If this is not done, then it becomes easy to design hulls with excellent seakeeping characteristics that require exorbitant amounts of power to achieve acceptable speeds. This seakeeping study makes the assumption that approximate methods for powering can be used in the selection of a cost effective seakeeping hull. Estimates of EHP using the method of J. Holtrop[1] were assumed to be appropriate because good agreement was found between Holtrop EHP estimates and open literature FFG7 powering data.[2]

The 20,000 SHP LM2500 gas turbine was selected as a "benchmark" powering system due to low specific weight, high reliability, ease in maintenance, fast start up times, and low manning requirements due to recent advances in automation.[3]

Loading considerations are beyond the scope of this report. It was assumed that typical open literature values for GM/B of 8% to 10% for the optimized scout fighter hull forms were appropriate.[4] Reasonable roll periods were required in the evaluation process.

Every Scout Fighter hull form has rudders and a centerline skeg. SASF hulls also had bilge keels. Full body hull forms were favored for the CLOSF because it was assumed that a flat bottom would facilitate docking in the well deck of the CLO. Bilge keels were not fitted on the CLOSF for the same reason.

CARRIER OF LARGE OBJECTS

The assumptions made for the CLO variants deal mainly with what appendages are attached and where motion points are located. Every CLO variant has bilge keels, a skeg, rudders, and propeller shaft brackets. The bilge keels are a third of the ship length in length and 4 feet (1.2 meters) wide. The skeg is located on the centerline. The rudders and propeller shaft brackets are located ≈16 feet (4.9 meters) off the center line. The propellers were assumed to be 21 feet (6.4 meters) in diameter, with the shaft center 10.5 feet (3.2 meters) above the rudder tip.

The speed selected for the optimization was 25 knots. The seakeeping study for the CLO was done without consideration of resistance and powering because the basic hull form was provided by the sponsor.

METHODOLOGY

The Seakeeping Optimization Program[5] was utilized to develop optimum seakeeping monohulls for the SASF, CLOSF, and CLO variants. This design program utilized an exponential random search method to find conventional monohulls with improved seakeeping characteristics. Hull forms were optimized for vertical motions in head seas. It was assumed that unacceptable lateral motions could be reduced through roll reduction technology such as bilge keels, anti-roll fins, rudder roll stabilization, etc. Optimization maximized the significant wave height that allowed a ship to operate without exceeding a specified set of pitch, vertical acceleration, and slam criteria. The parameters listed in Tables 1 and 2 were considered during the optimization process. The design process yielded the Scout Fighter seakeeping hull forms displayed in Figures 1 through 4. Due to a narrower set of design constants, CLO variant hull forms closely resembled the prototype hull form which was provided for this study. This body plan is displayed in Figure 5.

An evaluation of operability was performed using the Seakeeping Evaluation Program (SEP)[6]. Calculations of operability for the winter season were performed at North Atlantic Ocean locations for longcrested seas and were compared with representative United States Navy combatants utilizing a uniform set of ship motion limits which are applicable to transit operability. The selection of uniform ship motion limits allowed differences in seakeeping operability to reflect differences in hull design. The use of longcrested seas in this evaluation made it easier to identify specific motion problems. The Scout Fighters were compared with the FFG7 with anti-roll fins, a deep V hull form, the DD963, and DDG51. The CLO was compared with the AOE1, LHD1, LHA1, and CV41.

Transit operability calculations for Percent Time of Operability (PTO) in the North Atlantic Ocean were performed. Operability calculations were made in 15 degree increments with respect to heading at speeds ranging from 0 to 30 knots in 5 knot increments. These calculations gave equal weight to all heading and speed combinations based on the assumption that all combinations were equally likely to occur. The following ship motion limits were applied to each hull form during the operability calculations[7]:

CRITERION	LIMIT
Roll	8.0° Significant Single Amplitude
Pitch	3.0° Significant Single Amplitude
Wetness at station 0	30.0 per hour
Slams at station 3	20.0 per hour
Propeller Racing	90.0 emergences per hour
Vert Acceleration	0.4 g's at the Pilot House
Lat Acceleration	0.2 g's at the Pilot House

To facilitate an assessment of seakeeping performance in northern latitude regions, two geographic locations were selected for operability comparisons. The first location is the GIUK gap at 61°N; 15°W. The second location is in the North Atlantic Ocean at 56°N; 27°W. Operability comparisons are displayed in Tables 3 and 4. The performance figures listed represent values for the winter season based on environmental data supplied by the Spectral Ocean Wave Model (SOWM) data base. The SOWM data base contains archived wind data used by the Fleet Numerical Oceanography Center (FNOC) to hindcast wave fields for approximately 1500 locations (grid points) throughout the northern hemisphere. The values for percent time of operability are best used for relative comparisons between hull designs rather than absolute values of operability. The third section of each table describes the limiting seakeeping criteria along with normalized values which describe the percent time each criteria contributes to a reduction in operability at the GIUK gap location.

RESULTS

STAND ALONE SCOUT FIGHTER

Stand Alone Scout Fighter PTO calculations are displayed in Table 3. Similar calculations are also displayed for the FFG7 with active anti-roll fins, the KEHOE/SERTER[4] 4500 ton DEEPV hull, the DD963, and the DDG51. Table 3 illustrates two points. First, seakeeping optimization has the potential to produce hull designs which are expected to be superior to existing hulls in terms of operability. (Although the DDG51 is thought to have been designed with excellent seakeeping capability, the political decision to limit its length was harmful to this effort.) Second, a noticeable trend exists between an increase in displacement and an increase in PTO. The most promising hull forms for the Scout Fighter Project appear to have displacements ranging between 4,000 and 6,000 LT.

It is recommended that the 6000 ton Scout Fighter (SF6K) and the 4000 ton Scout Fighter (SF4K) remain in the selection process for the Stand Alone Scout Fighter. Powering estimates using the J. Holtrop calculations indicate that 30-knot speeds might be achieved using two 20,000 SHP LM2500 gas turbines on the 6000 ton model. (DD963's have four LM2500's while FFG7's have two.) Holtrop powering estimates at a speed of 32 knots were compared to published powering estimates for the 4500 ton DEEPV hull[4]. Both the 6000 ton and 4000 ton Scout Fighters seem to be superior to the 4500 ton DEEPV hull. (A formal powering investigation must be performed to confirm this.) Four LM2500's on the 6000 ton Scout Fighter would allow power to spare in the 30+

knot speed range. Two LM2500 gas turbines might comfortably power the 4000 ton Scout Fighter at 33 knots.

CLO LAUNCHED SCOUT FIGHTERS

A second class of scout fighters (CLOSF) which are capable of well deck launch and recovery from a CLO was briefly considered for this study. The dimensional limits displayed in Table 2 were taken from CLO well deck size estimates. One hull form for the CLOSF is displayed in Figure 4. PTO calculations are displayed in Table 4. Although only one hull form is presented, it is believed that other hull forms of similar displacements will have similar values for transit operability. PTO calculations could be improved if bilge keels, anti-roll fins, or a rudder roll stabilization (RRS) system was installed on this hull form. The use of bilge keels or anti-roll fins does not seem practical for a small vessel which must dock into the well deck of a COL. The use of an RRS system might prove to be a practical solution because no additional appendages would be required.

CLO Scout Fighters also are subject to limits in well deck launch and recovery operations with the mother ship. Criteria limits for CLO well deck launch and recovery have not been calculated. An educated guess for well deck launch and recovery based on personal experience with well deck operations in landing craft indicate that Sea State 3 will probably be an upper limit for launch and recovery.

CLO VARIANTS

Due to the large size of the variants, the rather lenient transit mission criteria set allows the operability to be very high as seen in Table 5. The percent time operability increases with length and displacement. The roll limit is exceeded much more than any other limit and the ships with the highest PTO are limited by roll the least. All the large ships seem equivalent in exceeding the pitch limit. The operabilities of the LHD1 and LHA1 should be the closest to the CLO variants, because their hull forms seem to be very similar, but they are not. (See Table 6.) All the CLO variants have similar PTOs which is to be expected considering the constraints used when optimizing. The unoptimized CDA hull form is actually better than any of the optimized variants.

The disappointing performance is due to the difference in natural roll period as shown in Table 7. The natural roll period changed among the CLO variants because KG remained at a fixed value. The optimized CLO hull forms had large waterplane areas which resulted in stiffer roll responses. The CLO variants and the AOE1 have roll periods near the peak frequencies of all but the highest sea states. This means they will have large roll values more often, because the lower sea states are more probable than the higher ones. All of this results in lower PTOs for the CLO variants and the AOE1.

RECOMMENDATIONS

PTO calculations suggest that a 4000-ton or 6000-ton Stand Alone Scout Fighter design may provide superior performance in terms of seakeeping and operability. CLO launched scout fighters will suffer in performance due to their small size and difficulties encountered during launch and recovery from a well deck. Autonomous vehicles will have similar difficulties as the CLO scout fighter, but might be able to tolerate higher Sea States if equipment is installed to take the punishment of heavy seas.

The shape of the optimized CLO hull forms follow the trends of other optimized monohulls. The water plane is very large, with the longitudinal center of flotation located aft of midships. Conversely the longitudinal center of buoyancy is located forward of midships. The bow stations are V-shaped, while the stern stations are flat and shallow. This means that most of the volume is forward while most of the water plane area is aft.

The optimal CLO variants, the CDA0, CDA1, CDL0, and CDL1, have lower operabilities than ships of similar size and mission. The low operabilities are due to poor roll performance. So any means to improve the roll performance, such as increasing the roll dampening and/or increasing the roll period, will increase operability. Some obvious methods are anti-roll fins or tanks, rudder roll stabilization, increasing KG, or decreasing the water plane area.

The stiffness in roll is characteristic of optimized hull forms, because the water plane area is maximized to reduce pitch regardless of what the consequences are for roll. The larger metacentric height due to the increased waterplane should allow the center of gravity to increase while still maintaining adequate stability. As indicated by these results, a stiff roll response may not be desirable.

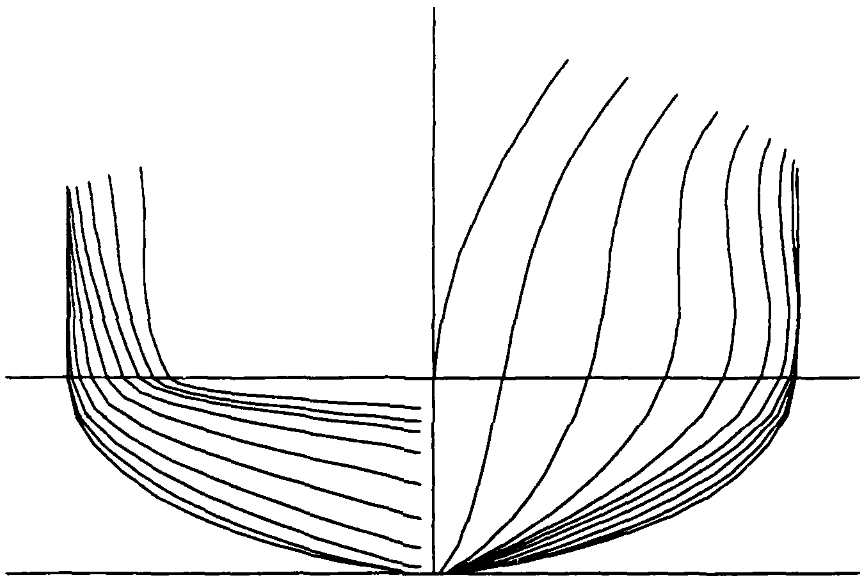

Fig. 1. 6000 LT Scout Fighter Body Plan.

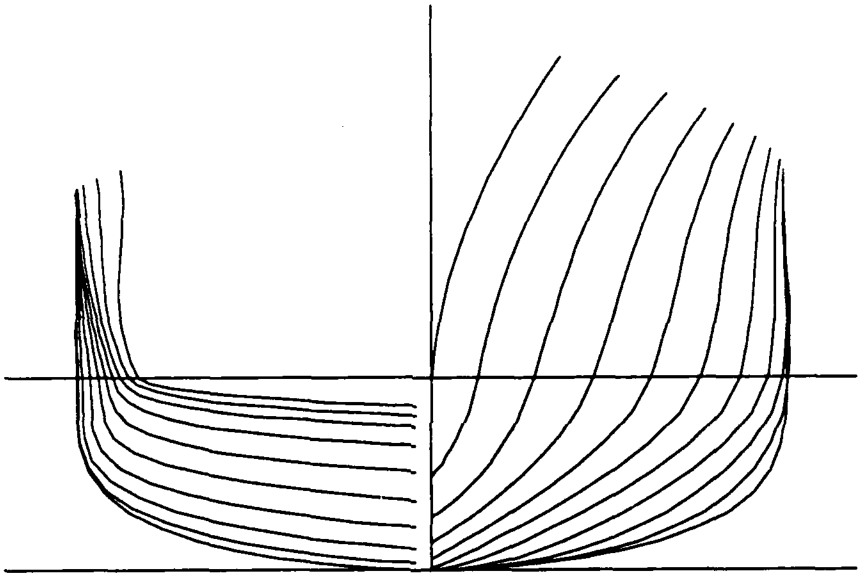

Fig. 2. 4000 LT Scout Fighter Body Plan.

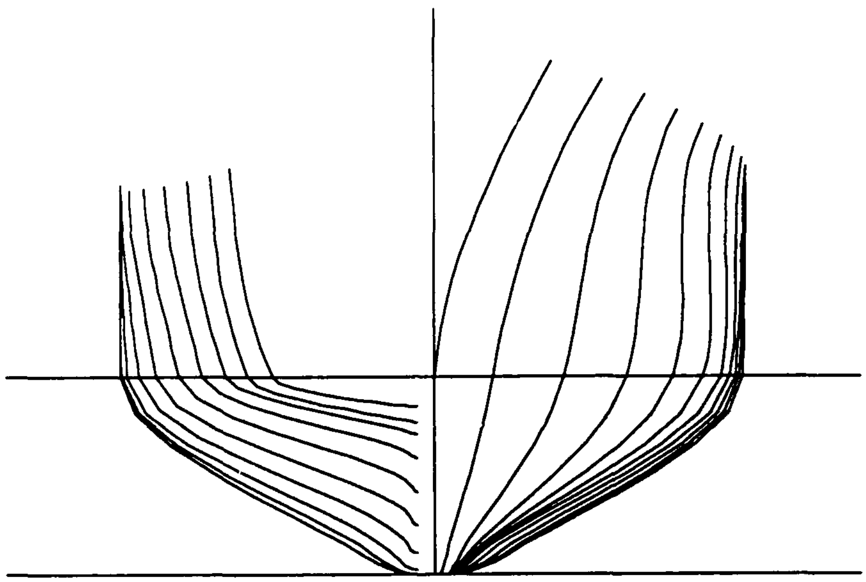

Fig. 3. 2000 LT Scout Fighter Body Plan.

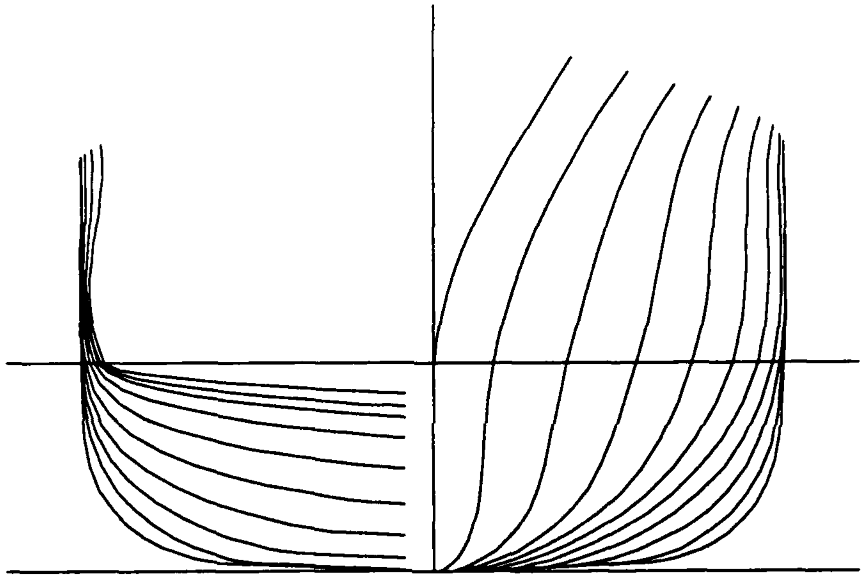

Fig. 4. 438 LT CLO Scout Fighter Body Plan.

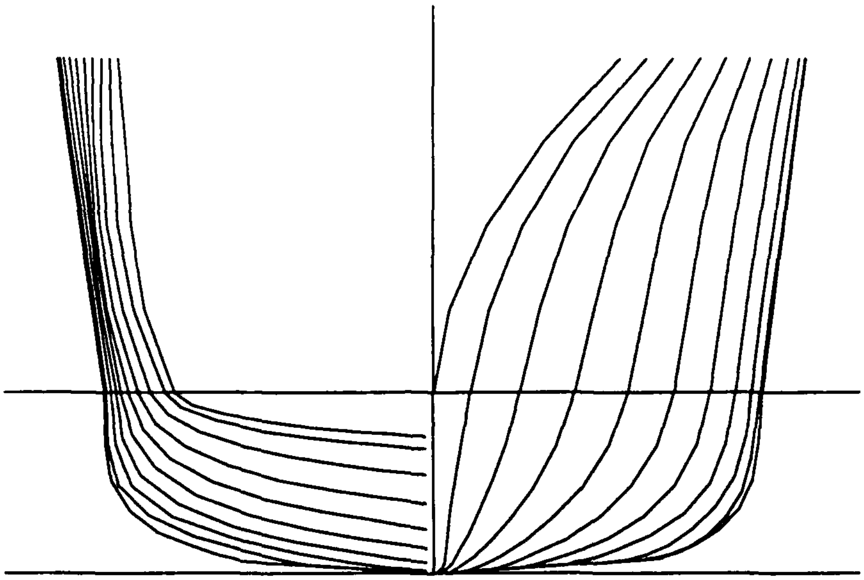

Fig. 5. CDA Body Plan.

Table 1. SASF Seakeeping Optimization Program (SKOPT) input parameters.

STAND ALONE SCOUT FIGHTERS

- Geometric Constraints

Parameter	Range of Values†
C_{WPF}	.400 to .800
C_{WPA}	.400 to 1.000
C_{VPF}	.600 to .800
B	15 to 150 ft
T	6 to 45 ft
C_M	0.400 to 1.000
L	150 to 700.00 ft
Δ	2000, 4000, and 6000 LT
L/B	4.00 to 10.00
L/T	20.00 to 35.00
B/T	2.50 to 4.10

- Motion Criteria

Pitch Limit	3.0° Significant Single Amplitude
Slam Limit	20.0 keel slams/hr at the station 3 keel
FP Vertical Acceleration Limit	0.55 g's
MS Vertical Acceleration Limit	0.40 g's

†Note: 1 foot= 0.3048 meters.

Table 2. COLSF Seakeeping Optimization Program (SKOPT) input parameters.

CLO LAUNCHED SCOUT FIGHTER

- Geometric Constraints

Parameter	Range of Values†
C_{WPF}	.400 to .800
C_{WPA}	.400 to 1.000
C_{VPF}	.600 to .800
B	9 to 25 ft
T	3 to 17 ft
C_M	0.880 to 1.000
L	150 to 360.00 ft
Δ	10 to 2000 LT
L/B	4.00 to 10.00
L/T	20.00 to 35.00
B/T	2.00 to 4.10

- Motion Criteria

Pitch Limit	3.0° Significant Single Amplitude
Slam Limit	20.0 keel slams/hr at the station 3 keel
FP Vertical Acceleration Limit	0.55 g's
MS Vertical Acceleration Limit	0.40 g's

†Note: 1 foot= 0.3048 meters.

Table 3. SASF Winter North Atlantic Ocean seakeeping comparison.

SASF Seakeeping—Transit Mission

• Ship Characteristics†

	SF2K	FFG7 fins	SF4K	DEEPV	SF6K	DD963	DDG51
Disp (LT)	1994	3790	3994	4591	5986	8195	8426
Length (ft)	367	408	465	425	530	529	466
Beam (ft)	38	45	49	46	56	55	59
Draft (ft)	12	15	13	15	15	20	21

• Percent Time Operable, Winter, Mobility Mission

	SF2K	FFG7 fins	SF4K	DEEPV	SF6K	DD963	DDG51
GIUK Gap[1]	51	66	76	73	81	71	66
Open N. Atl.[2]	41	57	67	65	73	62	56

• Percent Time Limited by each Criteria (GIUK Gap)

	SF2K	FFG7 fins	SF4K	DEEPV	SF6K	DD963	DDG51
Roll (8°SSA[3])[4]	33	19	12	14	11	18	24
Pitch (3°SSA)	13	12	8	9	5	6	10
Wetness (30/hr)	0	0	0	0	0	0	0
Slams (20/hr)	1	2	4	0	3	1	0
Racing (90/hr)	0	0	0	1	0	0	0
Vert acc (0.4g)[5]	2	1	0	3	0	4	0

[1](61°N 15°W) [2](56°N 27°W) [3]Significant Single Amplitude
[4]Limiting value [5]Pilot House †Note: 1 foot= 0.3048 meters.

Table 4. CLOSF Winter North Atlantic Ocean seakeeping estimates.

COLSF SEAKEEPING–Transit Mission

- Ship Characteristics†

	COLSF
Disp (LT)	438
Length (ft)	150
Beam (ft)	25
Draft (ft)	8

- Percent Time Operable, Winter, Mobility Mission

GIUK Gap[1]	29
Open N. Atl.[2]	21

- Percent Time Limited by each Criteria (GIUK Gap)

Roll (8°SSA[3])[4]	37
Pitch (3°SSA)	27
Wetness (30/hr)	0
Slams (20/hr)	0
Racing (90/hr)	0
Vert acc (0.4g)[5]	7

[1](61°N 15°W) [2](56°N 27°W) [3]Significant Single Amplitude
[4]Limiting value [5]Pilot House †Note: 1 foot= 0.3048 meters.

Table 5. CDA Winter North Atlantic seakeeping comparison.

CDL/CDA Seakeeping—Transit Mission

	CDL0	CDL1	CDA0	CDA1	CDA	AOE1	LHD1	LHA1	CV41
GIUK Gap[1]	87	85	85	88	92	87	96	90	97
Open N. Atl[2]	81	80	80	83	87	81	94	85	95
•Percent Time Limited by each criterion at GIUK GAP									
Roll (8° SSA[3])	12	14	14	10	6	10	2	9	2
Pitch (3° SSA)	1	1	1	2	2	3	1	1	1
Slam (20/hr)	0	0	0	0	0	0	1	0	0
Wetness (30/hr)	0	0	0	0	0	0	0	0	0
•Percent Time Limited by each criterion at Open N. Atl									
Roll (8° SSA)	16	18	18	14	8	14	3	13	2
Pitch (3° SSA)	3	2	2	3	4	5	2	2	3
Slam (20/hr)	0	0	0	0	1	0	1	0	0
Wetness (30/hr)	0	0	0	0	0	0	0	0	0

[1] (61°N 15°W) [2] (56°N 27°W) [3]Significant Single Amplitude

Table 6. Comparison of CDA principle dimensions and form coefficients.

	CDL0	CDL1	CDA0	CDA1	CDA	AOE1	LHD1	LHA1	CV41
LBP (ft)†	730.00	730.00	730.00	730.00	730.00	788.00	778.00	778.00	900.00
B (ft)	105.00	105.00	105.00	105.00	105.00	108.00	106.00	106.00	121.00
T (ft)	38.09	36.60	34.51	29.40	29.40	38.70	26.40	25.77	35.88
Δ (LT)	43,527.0	43,517.1	34,526.0	34,554.5	35,029.0	53,473.8	40,042.0	38,527.9	65,855.4
C_b	0.522	0.543	0.457	0.537	0.543	0.568	0.716	0.701	0.590
C_p	0.561	0.638	0.622	0.655	0.611	0.577	0.671	0.665	0.596
C_{vp}	0.612	0.634	0.547	0.626	0.512	0.783	0.861	0.843	0.810
C_m	0.931	0.852	0.735	0.820	0.890	0.984	0.959	0.945	0.989
C_{wp}	0.852	0.857	0.837	0.857	0.780	0.725	0.832	0.832	0.728
C_{wpf}	0.718	0.727	0.736	0.729	0.638	0.605	0.676	0.677	0.603
C_{wpa}	0.986	0.986	0.938	0.985	0.913	0.842	0.977	0.977	0.849
C_{vpf}	0.733	0.716	0.652	0.729	0.5753	0.893	0.898	0.876	0.911
C_{vpa}	0.524	0.574	0.464	0.550	0.449	0.698	0.685	0.675	0.733

†Note: 1 foot= 0.3048 meters.

Table 7. Comparison of CDA roll motion parameters.

	CDL0	CDL1	CDA0	CDA1	CDA	AOE1	LHD1	LHA1	CV41
KM (ft)†	58.26	57.73	63.23	62.37	53.41	45.66	54.83	56.05	51.80
KG (ft)	39.50	39.50	41.40	41.40	41.40	32.70	45.18	40.30	42.41
GM (ft)	18.79	18.23	21.83	20.97	12.01	12.96	9.65	15.75	9.39
T_ϕ (sec)	12.03	12.01	11.09	11.34	14.60	10.82	18.58	14.50	18.32
Bilge Keel span	4.00	4.00	4.00	4.00	4.00	4.25	4.00	4.00	5.00
Bilge Keel length	243.34	243.34	243.34	243.34	243.34	197.00	265.57	203.84	304.00

†Note: 1 foot= 0.3048 meters.

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